LA-UR -89-1305

Received by OSTI

MAY 0 9 1989

LA-UR--89-1305

DE89 011174

TITLE: MODELLING OF THE ANGULAR REFLECTANCE OF AN ARTIFICIAL PLANT CANOPY NEAR THE RETROREFLECTION PEAK IN THE OPTICAL REGIME

AUTHOR(S): CHRISTOPH C. BOREL
B.J. POWERS
S.A.W. GERSTL

SUBMITTED TO: IGARSS '89 12th CANADIAN SYMPOSIUM ON REMOTE SENSING FOR PRESENTATION AND PROCEEDINGS, VANCOUVER, CANADA, JULY 10-14, 1989

APRIL 1989

Los Alamos

Los Alamos National Laboratory
Los Alamos, New Mexico 87545

MODELING OF THE ANGULAR REFLECTANCE OF AN ARTIFICIAL PLANT CANOPY NEAR THE RETROREFLECTION PEAK IN THE OPTICAL REGIME

C.C. BOREL, B.J. POWERS, AND S.A.W. GERSTL

LOS ALAMOS NATIONAL LABORATORY
T-DOT, MS-K723
LOS ALAMOS, NEW MEXICO 87545, USA

Abstract

The narrow intensity peak in the reverse solar direction , also called the canopy hot spot or Heiligenschein, is studied using a artificial canopy. Polar Fourier analysis is proposed to classify asymmetric peaks for various canopy architectures.

Keywords: Angular Signatures, Plant Canopy Modelling, Hot Spot Analysis

1 Introduction

Vegetation-covered surfaces exhibit a narrow intensity peak in the reverse solar direction which is called the Heiligenschein, canopy hot spot or opposition effect. This peak is due to the total absence of shadows when the observation direction coincides with the solar direction. Previous studies indicate that the reflected angular distribution is related to the plant canopy architecture and the size of the illuminated objects (Gerstl and Simmer, 1986); and that the angular width does not change significantly under different atmospheric conditions (Powers and Gerstl, 1988). The angular intensity distribution has been used to estimate surface parameters on the moon (Hapke, 1963) and the particle size in the rings of Saturn (Lumme, 1971). Similarly, we expect that the canopy hot spot could be used to identify different plant species and their state of growth. However little is known on how canopy parameters like leaf size, leaf shape, leaf orientation and spatial leaf distribution affect the angular intensity distribution. Since natural plant canopies are very difficult to characterize an precise measurement conditions are difficult to reproduce due to plant growth, it was decided to simulate and build an artificial canopy structure. This artificial canopy allows us to control the canopy parameters in a systematic way and study the hot spot effect free from environmental and biological interferences.

2 Artificial Canopy Experiment

The Artificial Canopy Experiment (ACE) is performed in three stages:

1. Simulate by computer generated imaging the reflectance from a deterministic canopy with given leaf positions, leaf angles, leaf sizes and leaf shapes.
2. Build an artificial canopy using circular discs of 5 cm diameter arranged in up to 15 layers within a 3 m x 3 m x 1.5 m structure.
3. Measure the angular reflectance distribution of the artificial canopy in the vicinity of the retro solar direction using a CCD array camera.

A computer program to generate images of a given canopy using ray tracing was developed. The canopy is specified by entering the disc radius, the number of layers and how many leaves in both horizontal directions (x,y), the distance between leaves in x,y,z directions, and the leaf normal (or leaf angle) distribution. From this input the program creates the leaf center coordinates and leaf normal vectors. It was found that a regular canopy with constant leaf distances and leaf sizes when viewed from certain directions produces regular patterns, e.g. lines of leaves separated by dark lines of shadowed leaves and/or ground. These artifacts could make the analysis of the reflected angular intensity distribution extremely difficult, since many different views would have to be averaged together. To avoid the problem of these artifacts, the position of the leaves needed to be randomized.

The developed computer program creates two images of the canopy. The first image shows which leaves are visible by an observer at infinity using parallel projection. The second image is a computed picture as seen from a given point in space using a perspective projection. Rays are traced to the leaves, and intersections are found. Each intersection is tested as to whether it is also visible from infinity. If so, that point is considered illuminated otherwise a shadow occurs. The images are stored and displayed on an Image Processing System.

An example of an artificial canopy with 29 x 29 leaves in 15 layers is shown in Figure 1. The radius of the disks was 2.5 cm, the horizontal (x,y) and vertical (z) spacing was 10 cm with a random offset of ± 2 cm in x,y and z directions. The leaf area index for this canopy is about 3. The leaf normal was constant for all leaves with zenith angle $\theta_l = 60^0$ and azimuthal angle $\phi_l = -10^0$. The sun and view direction was chosen such

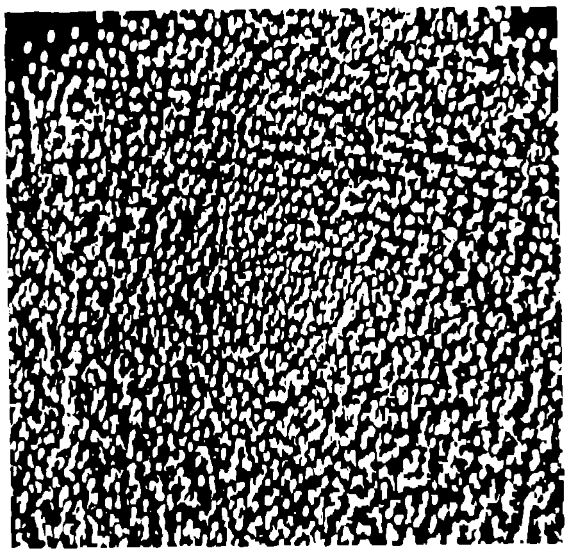

Figure 1: Computer generated image of an artificial canopy

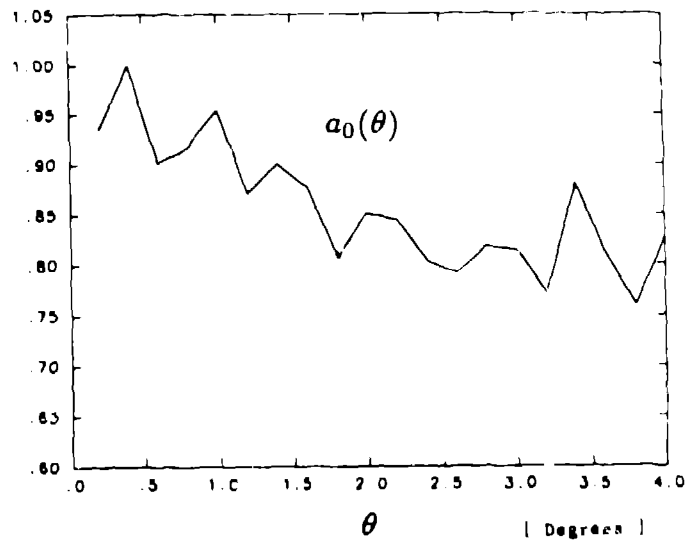

Figure 2: Radially averaged and normalized intensity $a_0(\theta)$ for a computer generated hot spot image

that the circular leaves appear as ellipses with a zenith angle $\theta = 34^0$ and an azimuthal angle $\phi_l = 60^0$ with the viewpoint at a distance of 5 m away from the center of the top canopy layer. The diagonal view angle as measured from the lower left to the upper right corner of the picture is 15 degrees. The brighter region in the center is the hot spot which is elongated in the vertical. Away from the center leaves cast shadows onto other leaves (black regions).

3 Hot Spot Analysis

Hot spot photographs taken from airplanes and computer generated images have been analyzed by retrieving the pixel intensity profile along a traverse passing through the center of the hot spot (Gerstl, 1988). The results show a very noisy intensity profile and it is difficult to fit a smooth angular distribution through the data points. Better results for circularly symmetric hot spots are obtained by the following method :

1. Find and mark the center of the hot spot, $\vec{C}$.
2. Compute a histogram of the average pixel intensity along concentric circles as a function of distance from $\vec{C}$. $a_0(\theta_i)$ where θ_i is the angle between the retro solar direction and the view direction, proportional to the circle's radius.

Figure 2 shows the average radial intensity for the simulated hot spot image shown in Figure .

Some vegetation covered surfaces exhibit an asymmetrical hot spot, e.g. grass (pasture) shows a vertically (arbitrary chosen y direction) elongated hot spot. A simple extension of the above method can describe this asymmetry of the hot spot. The pixel values in a given annulus between $\theta_i = i\Delta\theta$ and $\theta_{i+1} = (i+1)\Delta\theta$ are expanded in a Fourier series along the azimuth ϕ

$$P(\theta_i, \phi) = a_0(\theta_i) + \sum_{j=1}^{N} [a_j(\theta_i)\cos(j\phi) + b_j(\theta_i)\sin(j\phi)], i = 1, \quad , M$$

where ϕ is the rotation angle from the horizontal (x) direction in the image, as shown in Fig. 3 and M is the number of annuli. Figure 4 shows the first four Fourier coefficients : $a_1(\theta_i)$; $b_1(\theta_i)$; $a_2(\theta_i)$; $b_2(\theta_i)$ for the elongated hot spot in Figure 1. The most important Fourier coefficients for a hot spot in are $a_0(\theta)$, $a_1(\theta)$ and $a_2(\theta)$. A negative $a_2(\theta)$ indicates a vertically elongated hot spot (see $a_2(\theta)$ in Figure 4 for $0. < \theta < 0.5^0$) , whereas a positive $a_2(\theta)$ would describe a horizonally extended Hot spot. Any asymmetry of the upper part to the lower part is expressed by a non-zero $a_1(\theta)$. Since the the asymmetry of the hot spot image in Figure 1 is hardly noticeable by eye-sight, the fourier coefficients do not exhibit dramatic differences. Averaging over independent images will reduce the randomness and show smoother curves.

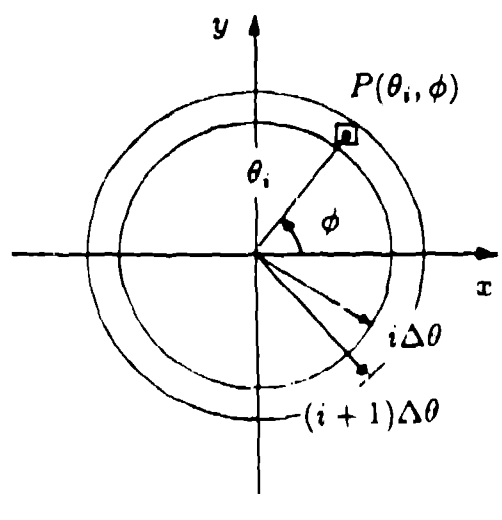

Figure 3: Geometry to analyze hot spot pictures

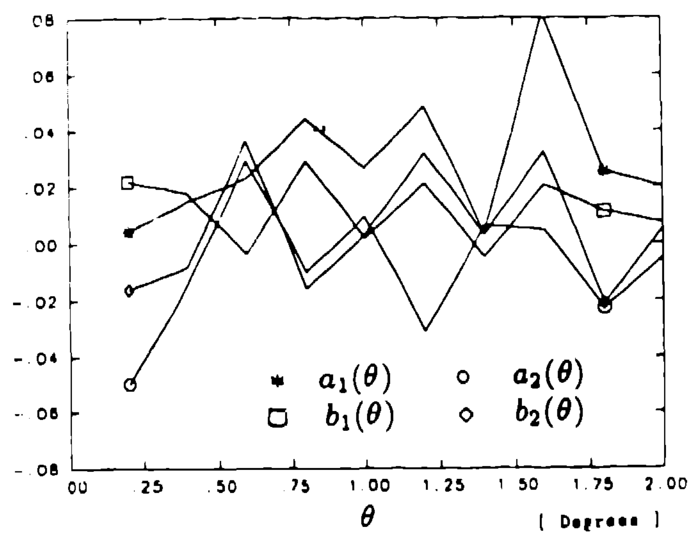

Figure 4: Fourier coefficients $a_1(\theta_i)$; $b_1(\theta_i)$; $a_2(\theta_i)$ and $b_2(\theta_i)$ for the computer generated hot spot image

4 Conclusions

An analysis method for asymmetric hot spots has been developped to analyze computer generated and experimentally obtained images of artificial canopies. A database with many angular signatures for various vegetation types and growth states could be used to estimate biophysical indicators for the growth state and type by finding the best fit. The artificial canopy will be used to provide more information on the functional dependency of the angular reflectance distribution on various structural canopy parameters.

References

Gerstl, S.A.W. and C. Simmer, "The Heiligenschein as a Diagnostic Tool in Satellite Remote Sensing," Topical Meeting on Meteorological Optics Technical Digest, 86:8 (Opt. Soc. Am., Wash. D.C. 1986), pp. 74-77 (1986). Also Los Alamos National Lab. report LA-UR-85-4098 (Nov. 1985).

Gerstl, S.A.W., "The Angular Reflectance Signature of the Canopy Hot Spot in the Optical Regime," Proc. 4th Int. Coll. on Spectral Signatures of Objects in Remote Sensing, Aussois, France (Jan. 1988). ESA report SP-287, pp. 129-132.

Hapke, B.W., "A Theoretical Photometric Function for the Lunar Surface," J. of Geophysical Research, 68, No. 15, pp. 4571-1586 (August 1963).

Lumme, K., "Interpretation of the Light Curves of Some Non Atmospheric Bodies in the Solar System," Astrophysics Space Science, 13, pp. 219-230 (1971)

Powers, B.J. and S.A.W. Gerstl, "Modeling of Atmospheric Effects on the Angular Distribution of a Backscattering Peak," IEEE Trans. on Geoscience and Remote Sensing, 26, No 5, pp. 649-659 (Sept. 1988).